

The Simultaneous Reduction of NO_x, PM, HC and CO from Large Stationary Diesel Engines Using SCR and Particulate Filters

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Johnson Matthey Stationary Source Emissions Control

Abstract

This paper is a case study in the simultaneous reduction of NO_x, PM, HC and CO from two large stationary Cummins diesel engines driving two 2 MW generators located at Snow Summit Mountain Resort in the South Coast Air Quality Management District in California. The required reductions are 85% of the PM, 25% of the HC, 50% CO, and 95% NO_x with a maximum of 10 ppm ammonia slip.

The exhaust from each engine passes through a three stage emissions control system. The first stage consists of an oxidation catalyst that converts CO and HC to water and CO₂. In addition, NO present from combustion is oxidized to NO₂. Stage two incorporates an array of large particulate matter (PM) or soot filters that trap the undesirable PM. The trapped PM is oxidized in the presence of NO₂ from stage one yielding CO₂. NO₂ that oxidizes the soot returns to NO at the completion of this continuous destructive cycle. The final stage reduces NO_x via an SCR reaction. A urea solution is injected into the exhaust and passes through a mixing duct transitioning to an SCR catalyst reactor for NO_x removal. The exhaust gas then exits the stack. There is no need for a muffler.

The systems were successfully commissioned in late 2003 and early 2004 and are working extremely well, meeting all emissions requirements.

Introduction

Snow Summit Mountain Resort offers a year round retreat for those who just want to get away from the hustle and bustle of everyday life. It also offers a number of activities for those that are adventurous or athletically inclined. The busiest time of the year for this resort is during the winter months when thousands flock to enjoy the best skiing that southern California has to offer. Just a short 2 hours drive from Los Angeles, Snow Summit, located at Big Bear Lake, offers 18 miles of ski trails. Since the area only gets an average of 75 inches of annual snow fall, Snow Summit actually makes an additional 36 to 60 inches of snow to cover the 240 acres of trails. Their snow making equipment converts 5,000 gallons of water per minute into snow. To power this system, Snow Summit must generate electricity onsite. Because of the remote location of this resort, it must be self-sufficient in meeting the bulk of its energy needs through distributed generation.



Courtesy of Snow Summit Mountain Resort

For many years Snow Summit rented portable power during the winter months in order to meet its energy requirements. This strategy proved to be costly and harmful to the environment. The rental diesel generators had no emission control equipment installed, and were emitting harmful NOx, CO, and Particulate Matter at a relatively high rate. In 2003 Snow Summit decided it would purchase generators for use during the winter months to make snow. The Cummins 2700DQLA generators, powered by Cummins QSK78-G6 diesel engines, were purchased through Cummins Cal Pacific, the Cummins Engine distributor located in Irvine, California. Because the Snow Summit Mountain Resort comes under the jurisdiction of the South Coast Air Quality Management District (SCAQMD), the air permit for the diesel engines required the installation of BACT (Best Available Control Technology) to control emissions from these engines.

Johnson Matthey has been a supplier of catalysts and engineered systems for controlling emissions from stationary engines for more than forty years. Of all the systems that have been designed and fabricated by Johnson Matthey, few have proved more challenging than the system installed at the Snow Summit Mountain Resort since the SCAQMD required a very high conversion of NOx as well as PM. The uncontrolled baseline emissions from the Cummins QSK78-G6 diesel engine, the SCAQMD regulated emissions levels and % reduction required are shown in Table 1.

Table 1. Cummins QSK78-G6 uncontrolled emissions and SCAQMD emissions limits

Emission	Baseline Levels	Regulation Levels	% Reduction Required
Nitrogen Oxides (NOx)	8.75 g/bhp-hr	0.60 g/bhp-hr	93.2%
Carbon Monoxide (CO)	0.72 g/bhp-hr	0.60 g/bhp-hr	16.7%
Hydrocarbon (HC)	0.20 g/bhp-hr	0.15 g/bhp-hr	25%
Particulate Matter (PM)	0.30 g/bhp-hr	0.045 g/bhp-hr	85%

The maximum ammonia slip is 10 ppmvd @ 15% O₂, and the target maximum pressure drop is 22 inches w.c. The exhaust flow from each 2899 hp engine is 17,225 acfm at 820 °F. The expected oxygen content is 9.5%.

With a palette of catalytic control technologies available to apply, Johnson Matthey chose to employ a combination of SCR (Selective Catalytic Reduction) for reducing NOx and a patented CRT[®] (Continuously Regenerating Technology) particulate matter filter system. This combined system marketed by Johnson Matthey as an SCRT[®] system has been proven to give very high conversions of NOx and PM. And, since the CRT[®] incorporates an oxidation catalyst upstream of the filter, very high reductions of CO and HC were also achieved.

In addition to supplying the SCRT[®] system, Johnson Matthey also provided a CRT-dm (diagnostic module). This data logging device constantly monitors exhaust gas backpressure and temperature. The primary objective of this device is to alert the operator that maintenance is required to keep the system within its peak operating efficiency. Finally, as a full service supplier, Johnson Matthey also provided engineering and start-up services.

CRT[®] and SCR Emissions Control Technologies

Each Cummins QSK78-G6 diesel engine was equipped with a Johnson Matthey SCRT[®] system, which includes a CRT[®] PM filter system and a separate SCR system.

CRT[®] PM Filter Technology – Johnson Matthey's patented CRT[®] filter system is a passive continuously regenerating particulate filter technology that incorporates a platinum catalyst upstream of a wall-flow ceramic filter. Soot collected in the filter is passively regenerated by the oxidation of NO₂. The NO₂ for this reaction is produced by the conversion of some of the NO in the exhaust stream to NO₂ by the precious metal catalyst upstream of the filter. Unlike other PM filter systems that incorporate an external heat source or a catalyzed filter, the CRT[®] system operates at significantly lower temperature. Depending on engine size, the CRT can be designed to include a matrix of catalysts and filters arranged in a round, square or rectangular configuration. The concept of a single filter CRT is shown in Figure 1.

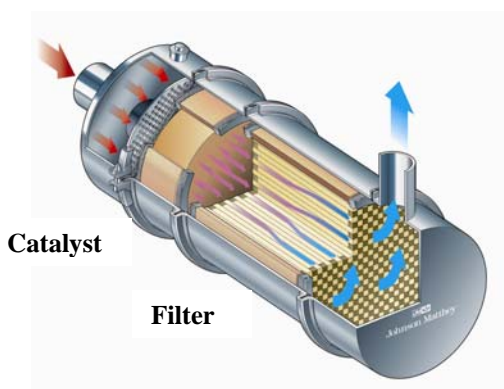
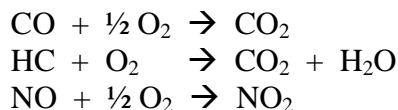


Figure 1. Patented CRT[®] PM filter system

Since the cells of the honeycomb filter are capped at the downstream end, exhaust cannot exit the cell directly. Instead, exhaust gas passes through the porous walls of the filter cells. In the process, particulate matter is deposited, or trapped, on the upstream side of the cell wall. Cleaned exhaust gas exits the filter to the right. In the CRT, the exhaust enters through the catalyst, where the following reactions occur:



The soot is collected in the filter where it is reacted with the NO₂ according to the following reaction:

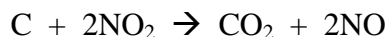


Figure 2 shows a graphical representation of these reactions.

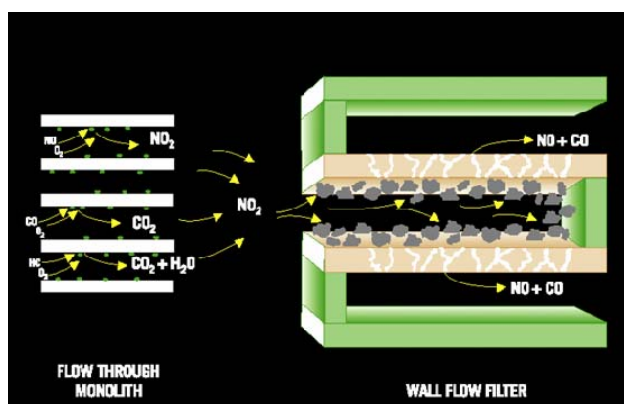


Figure 2. CRT[®] PM Chemistry

The NO₂ continuously reacts to oxidize the soot thereby keeping the filter clean of soot. Soot particles, which comprise carbon, SOF (soluble organic fraction), sulfate & water and ash are thus converted through the CRT as shown in Figure 3, with the ash remaining trapped in the filter. The ash must be removed physically by cleaning.

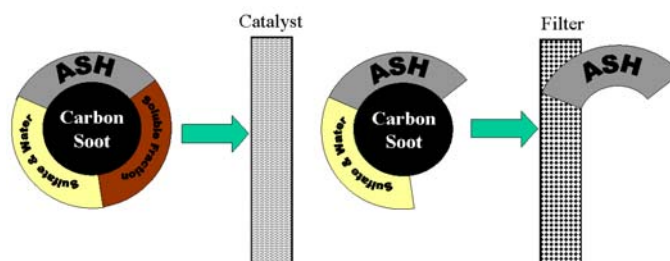
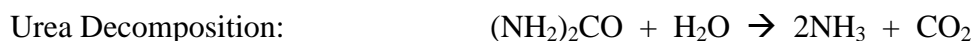


Figure 3. Particulate conversion through the CRT[®]

Urea SCR Technology – To control NO_x emissions from a diesel engine, which produces a lean exhaust, a reactant such as ammonia must be introduced to the exhaust gases in order to react with the NO_x reducing it to nitrogen. Urea, commonly used in the manufacture of fertilizers, can be easily decomposed to ammonia for this purpose. Urea crystals are readily dissolved in water to form a solution for injection into the exhaust stream. The urea decomposes through hydrolysis to form ammonia. The ammonia then converts the NO_x in the hot exhaust according to the following equations:



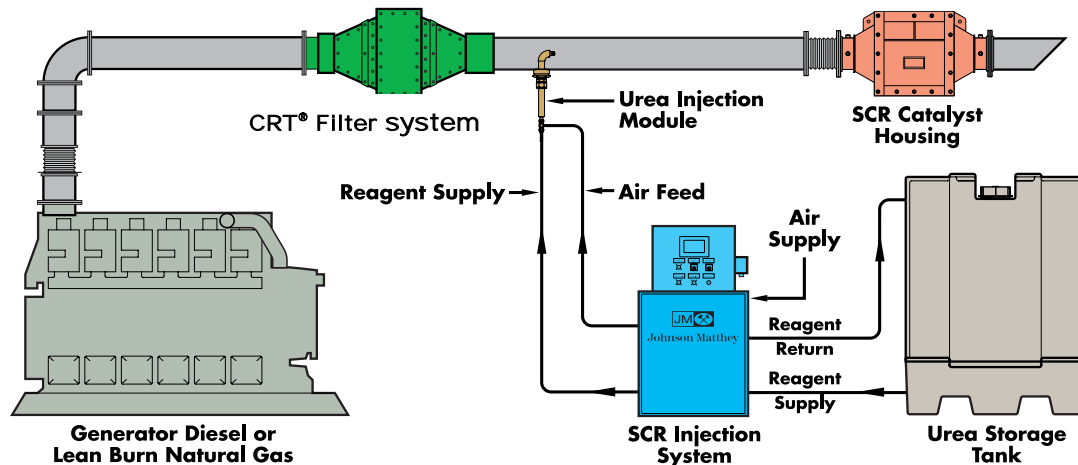


Figure 4. Urea injection system, urea supply & control system and SCR catalytic converter

High Performance Urea Injection System – The Johnson Matthey urea injection system uses a two-fluid technology of urea and compressed air. Urea is introduced into the center of the exhaust piping, prior to the catalyst surface, using an injection nozzle attached to a specially designed injection module mounted in the exhaust.

Compressed air is used for atomizing urea to the proper droplet size and prevention of urea crystal deposits in the lance or exhaust before, during and after engine shutdown. A PEMS (Predictive Emissions Monitoring System) or CEMS (Continuous Emissions Monitoring System) can be used to control the proper amount of urea to be injected. In a PEMS, NO_x levels are mapped along with several engine operating parameters such as RPM and engine load. These engine parameters are then used to predict the amount of NO_x and therefore the amount of urea. In a CEMS, the amount of urea is determined by an actual NO_x measurement. In the Snow Summit application, an engine load vs. urea injection rate map is utilized and NO_x output is verified with CEMS.

The primary urea processing components consist of a 10-micron urea filter, a circulation heater with urea temp RTD, redundant single speed magnetic gear driven pumps, pressure regulating valve, precision turbine flow meter, control valve, pressure and flow monitoring transmitters and various solenoid valves. The urea is drawn from a storage tank through the filter by the primary pump, and is regulated to the required operating pressure. When all of the system permissives are met, including engine load and exhaust gas temperature, urea injection is automatic. The control system opens the proper valving, allowing urea to flow from the process panel to the injection nozzle modulated by a control valve and reported on the touch-screen in gallons/hour as monitored by a precision turbine flow meter. The control system adjusts the amount of urea flow to the injection nozzle as

required by the primary control loop. During the warm-up or cool down period, the urea is regulated and returned back to the urea storage tank, which also doubles as the freeze protection loop even if the engine is off. Pressure and flow devices are located throughout the system to aid in system diagnostics. The urea loop is supplied with internal manual shut off valves for maintenance or repairs.

The air delivery system contains all components required to monitor, regulate and distribute air as needed for proper urea atomization, insulating the urea injection module and nozzle, and to provide sufficient purge during a non-injection event. This includes such devices as filters, water separators, pressure regulators, flow meters, pressure transmitters and valves. . There is also a 3-way manual valve that is used for water purge if available. Purging the lines from the injection panel to the exhaust is critical in preventing urea crystallization at the nozzle and completely removing any traces of urea or water from the piping between the injection system and the exhaust, this eliminates the need for heat tracing. Following an engine shut down, the air purge is shut off by a programmable timer, thus reducing operating costs.

Urea Injection Control Panel – The injection system panel contains all of the electronics and hardware to control urea flow and air pressure to the Injection Module. This panel has two sections: electronic control processor in the top panel and the mechanicals in the bottom panel, as shown in Figure 5. The urea processing components are located along the bottom section of the lower panel, while the air delivery system is located in the top section of the lower panel.

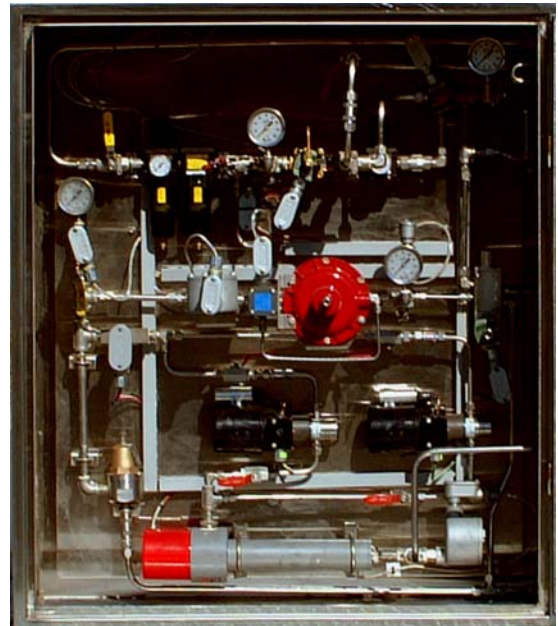


Figure 5. Urea injection process panel arrangement

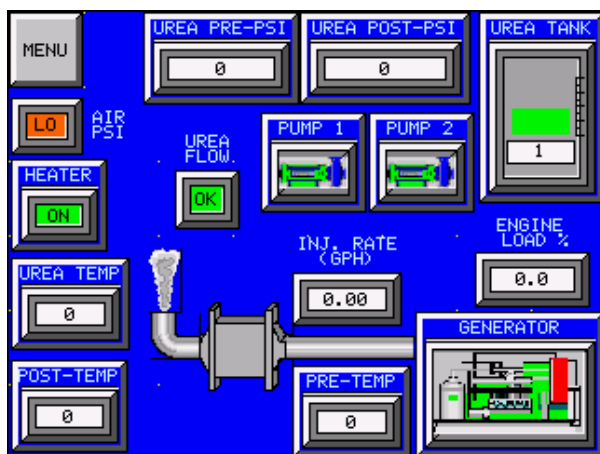


Figure 6. Urea injection control panel touch screen

The electronics located in the top portion of the panel include two PC based controllers, display/touch screen (see Figure 6) and all related wiring, switches, terminal blocks and power supplies. The

touch screen displays all of the relevant system parameters including engine load, urea flow, exhaust gas temperatures, exhaust system backpressure, and other miscellaneous system parameters. All operational parameters including injection rate curves and permissives are programmed through the touch screen.

Snow Summit Emissions Control System

The Cummins QSK78-G6 engines were equipped with Cummins Model 2700 DQLA generator sets and each system had a CRT[®] system, which contained a matrix of sixteen catalyst modules and sixteen filters arranged in a manner to minimize pressure drop. As seen in Figure 7, the exhaust flows through the CRT first, and then through a mixing chamber and into the SCR system. The SCR catalyst is installed after the CRT to protect the integrity of the SCR catalyst and prevent the conversion of ammonia to NO_x by the oxidation catalyst in the CRT. The SCR catalyst is supported on metallic monolith substrates that provide low pressure drop, high mechanical strength and high durability.

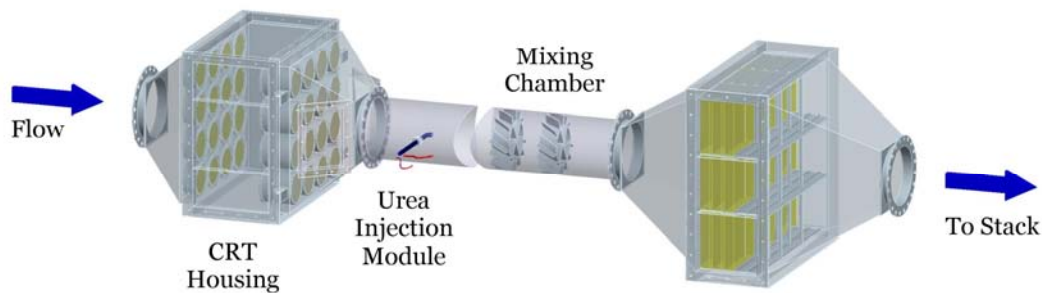


Figure 7. CRT and SCR arrangement

While the performance of the emissions control system was very technically demanding, the installation was not. The extremely capable engineering staff at Snow Summit installed all of the components. The most difficult part was getting all of the equipment up the mountain.

All of the equipment was installed indoors and there was more than adequate space. Figure 8 shows the CRT installed. The housing is insulated for safety and also to minimize heat loss. An access panel in the side of the housing allows for easy access to the filters for cleaning.

Figure 9 shows the SCR system installed. It contains several layers of catalyst, which are easily accessible through a side panel.



Figure 9. SCR system

Following a smooth and successful installation, both CRT[®] and SCR systems were started up in just two days. Snow Summit maintains remote monitoring of the system at the base of the mountain. Snow Summit operates the system only during the ski season, typically running 1200 to 1500 hours per season. To date, more than 2000 hours of run time have been accumulated and all emissions limits were achieved.



Figure 8. CRT PM filter system

Located beneath the SCR catalyst system is the urea injection control panel, which is shown in Figure 10.



Figure 10. Urea injection and process control panels

Emissions Testing Results

The emissions from each engine were tested by a third party. The results compared to the SCAQMD limits are shown in Table 3 and Table 4 for each engine. Note that each of the pollutants was reduced to levels well below their permit limits.

Table 2. Source test results for Engine #1

Pollutant	SCAQMD Emissions Limit @15% O₂	Actual Emissions	% Reduction Targeted	% Reduction Achieved
PM ₁₀	0.045 g/bhp-hr	<0.005 g/bhp-hr	85%	>90%
NO _x	50 ppm	34.90 ppm	93.2%	>94%
CO	89 ppm	24.22 ppm	16.7%	>90%
TNMEHC	39 ppm 0.15 g/bhp-hr	10.80 ppm 0.05 g/bhp-hr	25%	>75%
NH ₃	10 ppm	0.01 ppm		Surpassed

Table 3. Source test results for Engine #2

Pollutant	SCAQMD Emissions Limit @15% O₂	Actual Emissions	% Reduction Targeted	% Reduction Achieved
PM ₁₀	0.045 g/bhp-hr	<0.005 g/bhp-hr	85%	>90%
NO _x	50 ppm	44.27 ppm	93.2%	>94%
CO	89 ppm	3.62 ppm	16.7%	>90%
TNMEHC	39 ppm 0.15 g/bhp-hr	3.18 ppm 0.02 g/bhp-hr	25%	>75%
NH ₃	10 ppm	0.00 ppm		Surpassed

Conclusions

The Snow Summit engines are the first stationary engines in the nation to be required to meet extremely stringent NO_x and PM emissions limits. It is the first site to require a large array of CRT catalysts and filters and the first site where a particulate control system is used in conjunction with a complete SCR system on a large stationary engine. The low PM values, combined with the low NO_x, CO and HC emissions at the stack demonstrate that the criteria pollutants from a diesel engine can be simultaneously controlled by CRT[®] and SCR technologies.